Landcare Research
Manaaki Whenua
POLICY BRIEF

Planning for tipping points and enhancing resilience in production landscapes

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KEY MESSAGES

1. A social-ecological system, which emerges when people interact with the natural environment, can cross a tipping point to a self-reinforcing degraded state, leading to substantial and immediate losses of ecosystem services.

2. Tipping points are not rare, isolated phenomena. On the contrary, they are common features of many social-ecological systems. Still, tipping points have proven difficult to predict.

3. Transitions to degraded states may be irreversible. However, for some systems, appropriate policies can either facilitate a shift to a new, desirable state or prevent change in the first place. Key leverage points exist at which small inputs can break feedback loops that generate transitions to new states or promote feedback loops that create desired transitions.

4. Adapting resource use to small-scale changes builds resilience against catastrophic tipping points. Adequate scientific monitoring and system-specific expertise are essential for successful adaptive management.

CONCEPTS

The New Zealand government has ambitious plans to double primary industry exports in real terms from $32 billion in 2012 to $64 billion by 2025 and to increase the value of exports from 30% to 40% of the share of real GDP[1]. Achieving these targets will require the value of primary industries to grow by 5.5% annually, which will add pressure to New Zealand's ecosystems.

It is often assumed that gradually increasing pressure will not affect ecosystems significantly, or, at worst, that any environmental degradation can be reversed if the pressure is reduced. However, large, rapid, unanticipated and long-lasting changes have been documented in ecosystems throughout the world as human actions force ecosystems across their critical thresholds, commonly referred to as 'tipping points' (Figure 1).

When a 'social-ecological system' (SES) crosses a tipping point to a new 'state', there are often immediate adverse impacts on social and ecological systems, which are connected through human impacts and our dependency on the natural environment.

Restoration of SES that have crossed tipping points can be difficult or even impossible to achieve due to 'feedback effects' that maintain systems in undesirable 'vicious cycles', resulting in 'hysteresis'. Nevertheless, it may be possible to use 'leverage points' to either drive SES from degraded states to desirable states and/or to prevent them from reaching tipping points in the first place.

Framing New Zealand's resource management policies to anticipate tipping points, to prevent transitions to degraded states and promote shifts to desirable states will strengthen our capacity to build 'resilience' and to maintain productivity in the face of environmental and societal changes.

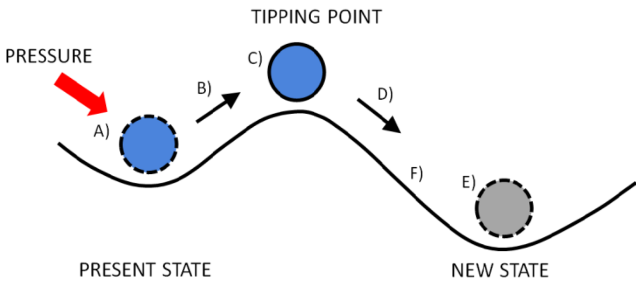

Figure 1.: The tipping point framework illustrates the capacity of a system to absorb pressure. A system remains within its current state (domain of attraction) as long as it is able to absorb pressure, even if small-scale changes continuously occur (A). However, the pressure can gradually or through a shock push a system to its limit (B), its' critical threshold. The system has now reached a tipping point (C): like a ball balancing on a hill, at this stage even a minor push is enough to cross the tipping point, upon which feedbacks accelerate the shift (D) into a new state (E). The new state is often characterized by irreversibility or high cost for returning back to previous state, which is illustrated in the figure as a ball being in a deep valley (E) with long uphill climb back to the previous state (F). An iconic example of state shift is lake eutrophication. Modified from [2].

TIPPING POINTS IN SOCIAL-ECOLOGICAL SYSTEMS

Accumulating evidence shows that tipping points and 'state shifts' can occur in diverse natural and production systems as well as social systems. Examples range from the eutrophication of freshwater lakes that are triggered by agricultural runoff to bank runs that are triggered by financial panic (Box 1). Moreover, feedback effects between the social and biophysical components of an SES can generate state shifts in one component due to pressures originating in the other (Table 1). Consequently, our understanding of how to anticipate tipping points and how to manage production systems for tipping points requires viewing them as features of an integrated SES.

After crossing a tipping point, a new state may function differently than the previous state, changing the outcomes of established management strategies. At the same time, there is potential for management interventions to shift a poorly functioning SES across a tipping point to a self-sustaining state. In some New Zealand examples, engagement of different stakeholders, use of harvesting quotas and a strong emotional connection to the local environment have successfully facilitated a shift from resource overuse to sustainable management.[6]

The vulnerability of an SES to undesirable tipping points can be reduced by building resilience, the capacity to persist in the face of change and to continue developing with ever-changing environments (Box 2). Fostering the ability to accommodate small-scale variability and perturbations reduces the likelihood of an SES succumbing to large-scale changes. For example, attempts to reduce natural variability have removed elements that buffer against change: removing species that buffer against drought or soil erosion reduces the long-term viability of ecosystem functioning and continuity in the supply of 'ecosystem services' such as food and timber provisioning. Similarly, more diverse economies have been shown to exhibit greater stability and resilience to economic shocks[7].

ACCOUNTING FOR TIPPING POINTS IN POLICY MAKING

The emerging approach for coping with tipping points is policy that has clear goals, adapts to change and focuses on resilience.

Several principles can be used to underpin policy:

1. *Establish policies centred on broad-based endorsement of the desired state(s) of an SES.* Although policies can be designed to promote change within an SES (e.g. to increase economic efficiency), it is necessary to establish social and ecological benchmarks to measure change in the state of an SES. In addition to benchmarks, it is necessary to set goals for maintaining an existing state within agreed boundaries (domain of attraction) or goals for transitioning to a desired state from a degraded state. Methods for setting benchmarks need to be consistent with metrics used to detect approaching tipping points.

2. *Build in mechanisms for detecting approaching tipping points.* In many systems, change slowly accumulates until it is abruptly released, resulting in reorganization of the SES. Indeed, evidence shows that a seemingly stable SES may undergo substantial internal change before stress becomes evident. Ways of detecting imminent tipping points – so

Box 1: Examples of Tipping Points

Freshwater eutrophication
Anthropogenic nutrient pollution acts as the main driver for eutrophication in shallow lakes, although eutrophication may take place even without human influence. Despite increasing nutrient concentrations, water clarity often seems to be hardly affected until a nutrient concentration tipping point is reached, and the lake suddenly shifts from a clear water state to a turbid water state.[2] Internal feedback mechanisms for nutrient recycling and food web interactions lock the system in the new, eutrophic state. Therefore, reduction of nutrient inputs may not reverse the shift. The eutrophic state is undesirable because it is associated with algal blooms, releasing toxins that can kill fish, birds and mammals. A potential leverage point for lake eutrophication is weed harvesting to disrupt nutrient cycling[3]. However, successful restoration attempts require in-depth knowledge of individual lakes. Several New Zealand lakes have undergone state shifts. The prevalence of the shifts appears to be associated with catchment use and exotic species[4].

Wall Street Crash of 1929
Before autumn 1929, American investors saw record returns and many people believed that the stock market would continue to rise. Rising share prices encouraged more people to invest, leading to further price rises (a social feedback). However, international crop markets faltered, causing agricultural overproduction and financial despair among American farmers. The London Stock Exchange crash weakened US optimism on overseas trade, and the American market became severely unstable. High consumer debt and decreased optimism led to intensive selling and finally to panic that resulted in a severe crash. Consumer spending and investment dropped, causing steep declines in industrial output and the failure of many banks. The new state – namely, the Great Depression – was characterized by uncertainty, consumer debt, high unemployment and significant loss of wealth. The recovery took longer than a decade, indicating hysteresis.

Baltic Sea cod boom and collapse
In the Baltic Sea, the cod fishery suddenly shifted in the 1980s from a state of historically high cod biomass and catches to an ecosystem state with low cod abundance. Recent research[5] suggests that the state marked by high abundance was ecologically unstable and instead was stabilized by feedbacks in the social system such as adaptive fishing that caused the cod boom to persist, at least temporarily. Eventually, ecosystem instability due to ecological feedbacks and human pressure became too high, and the ecosystem shifted to a new state with low cod abundance. The cod stock has still not fully recovered despite increased regulation, including quotas on fish catch.

Box 2: Resilience

Resilience refers to the capacity of a system to absorb disturbance and adapt while undergoing change so as to retain system functioning, feedbacks and identity.[8] If resilience declines, progressively lower pressures can cause the system to cross a tipping point into a new state.

In SES, resilience can be seen as the capacity to sustain human wellbeing and healthy ecosystems in the face of change by averting tipping points and by adapting and transforming in response to change. Two types of resilience are recognized: 1) rate-of-return resilience, which indicates how quickly the SES recovers after disturbance, and 2) domain-of-attraction resilience, which indicates the magnitude of disturbance that will shift the SES across a tipping point to a new state. To build and maintain resilience, SES must be managed for flexibility and adaptation rather than for control. Similarly, steering an SES to a desired tipping point requires creating conditions for new initiatives to emerge, recombining knowledge and experimenting and learning with change.

Research on social-ecological resilience has started to provide insights on which factors promote resilience[9]. Diversity, for example, is regarded as being important for resilience because it provides options for responding to various changes and perturbations. Similarly, broad participation in resource governance builds trust, promotes improved understanding on system dynamics and facilitates collective action. Understanding that SES are based on complex and unpredictable interdependencies can be seen as the first step for resilience-based policy making.

called early warning signals – include rising variability in ecological or social indicators (e.g., instability preceding the Wall Street Crash, Box 1). Identifying reliable early warning signals remains a challenge and is a critical area for new research.

3. *Design policies that acknowledge the costs or benefits of crossing tipping points in relation to inaction*. Because it is often difficult to detect or anticipate a tipping point with certainty, the risk of crossing one inadvertently must be balanced against the potential costs of a sudden shift to a new state. The greater the cost of a tipping point, the lower the risk that can be tolerated. Also, when trying to steer a system to a new state, the complexity of an SES and the close proximity to a tipping point can lead to substantial uncertainty in how the system will respond. Policies are more likely to be effective and the potential costs accepted when risks and outcomes are acknowledged and evaluated.

4. *Design policies that acknowledge feedback mechanisms within and between social and ecological components of an SES*. Instead of considering social and ecological systems separately, specific policies are required to avoid adverse outcomes of interconnecting feedbacks or the lack thereof. For example, in fisheries, by-catch species can be depleted when the rate of harvesting is based only on commercial quota species and not others in the ecosystem. Further, policies must be based on an understanding of why people use natural resources the way in which they do; i.e. policies can be designed to promote and reinforce beneficial human behaviour, strengthening rate-of-return resilience. If necessary, policies can promote new positive feedbacks, for example by creating new markets[10], that move an SES across a tipping point to a desired state.

5. *Promote resilience by accepting change and by learning, adapting and improving policies*. The vulnerability of an SES to reaching tipping points can be reduced by building resilience (Box 2). Fostering the capacity of an SES to absorb small-scale variability and change strengthens rate-of-return resilience and reduces the likelihood of large-scale changes. Attempts to reduce natural variability are based on expectations of maintaining a steady state. In contrast, adaptive management, when implemented properly[11], accounts for change by fostering learning and adaptation. By monitoring and by testing our understanding through experiments and innovation, adaptive management strives to learn continuously about the condition and behaviour of an SES. Policy continuously selects, communicates and implements appropriate solutions.

KNOWLEDGE GAPS

Knowledge of tipping points and their potential causes and effects within an SES is crucial for anticipating and reacting to local and global changes. The following list presents a series of questions for further discussion to foster understanding of tipping points and resilience in production systems.

SES states in a changing world. Can we reach agreement and define the boundaries on what constitutes a desirable SES state, especially when social and environmental conditions change? Different interest groups may view the same tipping points differently: Is there variation in the perception of and response to the tipping points?

Detecting approaching tipping points. What metrics are best for detecting approaching tipping points in an SES? Are these metrics sufficiently sensitive to provide early warning? Can tipping points be detected using existing monitoring methods and networks? If new methods are required, are they feasible and affordable?

System understanding. How much detailed knowledge of a complex SES is necessary for effective, evidence-based policies and management? For example, what are the feedbacks that can maintain an SES in the present state and which strengthened feedbacks lead to undesirable outcomes? Are our data adequate for identification of where tipping points are located?

Table 1. Examples of existing and potential tipping points and leverage points in New Zealand social-ecological systems

Desirable state	Undesirable state	Feedbacks that favour undesirable states	Potential leverage points and new feedbacks to *facilitate* beneficial tipping points or *avoid* undesirable tipping points
Wildling pines: Unproductive, pine-infested land[12]			
• Extensively-grazed, semi-natural grasslands 	• Grassland invaded by wilding conifer trees, eventually forming a forest 	• Biophysical: As invasion progresses, more trees provide a larger seed source and mycorrhizal fungal networks, which allow more rapid spread of wildings because each parent tree can produce more successfully colonizing offspring. • Social: More trees reduce land productivity and the capacity of managers to control the problem.	• Scientific: New control technology reduces the cost and provides landholders with feasible methods for removing wildings (weakens adverse social feedback). • Social: approval for alternative high-value land use justifies the cost of pine removal (creates new economic feedback).
Invasive mammals: Impacts on native species and ecosystems[13,14]			
• Healthy native ecosystems 	• Native flora and fauna threatened by invasive mammals 	• Social: Increasing realisation that effective pest management requires high levels of community support and landowner participation. • Biophysical: Trophic feedbacks support high-density populations of invasive species. • Biophysical: Continuing decline of indigenous species provides less resistance to further invasions. • Biophysical: Invasive species can facilitate establishment of further invasions. • Social: Perception that continued impacts of invasive mammals are inevitable. • Biophysical: Abundant invaders dominate the landscape, facilitating colonisation of new areas.	• Social: High-profile individuals promote a vision of predator-free New Zealand (creates new social feedback). • Political: Support for a sustained effort to achieve eradication of key predators by 2050 (breaks feedback associated with ongoing cost and effort). • Scientific: Focus on new technologies and strategies to achieve eradication rather than suppression of predators (breaks social feedback of inevitability). • Biophysical: Enhanced recovery of damaged natural ecosystems and opportunities for novel, sustainable ecosystems (e.g. viable populations of native species in human-dominated landscapes) increases the proportion of native propagules in the landscape (weakens biophysical feedback).

Desirable state	Undesirable state	Feedbacks that favour undesirable states	Potential leverage points and new feedbacks to *facilitate* beneficial tipping points or *avoid* undesirable tipping points
Production landscapes: Loss of connectivity in remnant native habitat[15]			
• Native habitat connected via natural corridors that facilitate dispersal and maintenance of viable population sizes of native species 	• Natural habitats fragmented within a landscape dominated by agriculture 	• Social: Policies facilitate agricultural intensification, generating expectations of higher production; advances in technology enable increased use of areas with low natural productivity, increasing pressure to change land use. • Biophysical: Clearing of native habitat reduces connectivity, imposing demographic and random processes that accelerate losses of indigenous species and ecosystem services. • Biophysical: A high perimeter-to-area ratio of fragmented forests facilitates encroachment by invasive weeds that inhibits regeneration of tree species. • Social: Changed perceptions of 'normal' agricultural landscapes lead to further clearing of natural areas. • Economic: Intensification requires debt to pay for infrastructure; forces prioritisation of short-term profit.	• Political: New policies reduce costs of restoring native habitat on private land (weakens adverse economic feedback). • Economic: Income generation (e.g. via carbon credits or honey production) promotes increasing restoration of native plant communities (creates new economic feedback). • Biophysical: Connectivity generated by habitat restoration results in rapid increase of native wildlife (ecological feedbacks), thereby enhancing seed-dispersal and regeneration/expansion of forest. • Social: Increased awareness of and exposure to iconic species reinforces public support for habitat restoration (feedback via reinforcing social norms). • Social: Social license to operate increases as owners meet community expectations for native vegetation (feedback via reinforcing social norms).
Farmed and wild deer: damage to alpine and sub-alpine ecosystems[16]			
• Viable farmed-deer industry with low-density wild deer populations in alpine and sub-alpine ecosystems 	• Alpine and sub-alpine ecosystems damaged by high-density wild deer populations sustained by refugia in sub-alpine forests 	• Social: If toxins are used to suppress growing wild deer populations, access to international markets declines due to perceptions that farmed venison could be contaminated, and opposition increases from recreational hunters. • Technical: Inefficient commercial harvesting in sub-alpine forests enables wild deer populations to spill over into alpine habitat. • Biophysical: Low harvesting pressure due to social and technical barriers allows continued increase in wild deer populations, with subsequent adverse impacts on native vegetation.	• Economic: Increasing use of helicopters for tourism subsidises commercial harvesting of wild deer in sub-alpine forest (breaks economic and technical feedback on commercial harvesting). • Economic: Promoting wild venison extends commercial harvesting to sub-alpine forest (breaks economic feedback on commercial harvesting). • Scientific: New control technology that can be isolated from farmed deer suppresses wild deer populations; reduces browse impacts on native vegetation (breaks economic feedback on farmed-deer industry; breaks opposition from recreational hunters).

Resilience principles. How do factors promoting resilience interact and depend on each other, and how should they be applied? Who benefits or loses from enhancing resilience of specific ecosystem services? Do our society and natural environment have unique attributes that can be bolstered to increase the resilience of production systems?

IN SUMMARY

Increased pressure on productive systems is predicted to increase the frequency at which systems cross critical thresholds and abruptly shift to new states. The SES perspective explicitly accounts for social and biophysical feedbacks that can precipitate tipping points. However, policies can be designed to decrease the risk of undesired tipping points or, where necessary, to facilitate transitions across tipping points to a new preferred state. Policy makers can cultivate New Zealand's capacity to adapt to change by fostering social and ecological resilience.

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GLOSSARY

Tipping point: Situation in which accelerating change is caused by a reinforcing feedback in one or more social or biophysical components of a system. At the tipping point, a small perturbation can trigger a system to transition to a new state. Also called 'critical threshold'.

Cycles – virtuous and vicious: A complex chain of events that reinforce themselves through feedback loops. A virtuous cycle has desirable results while a vicious cycle has undesirable results.

Ecosystem services: Benefits that people receive from ecosystems, including cultural values.

Feedback effect: A mechanism that modifies or controls a system; the outcomes generated by the mechanism are fed back as inputs. Negative feedback loops are self-correcting (i.e. they maintain a system in its current state), while positive feedback loops are self-reinforcing (i.e. they drive a system away from its current state).

Hysteresis: Situation in which the threshold to be crossed to return to the previous state is different to the threshold crossed when moving out of that state in the first place

Leverage points: Places within a complex system in which a small change can produce large changes in the wider system.

Resilience: Capacity of a system to absorb perturbation and stress without losing its fundamental functions, structure, identity and feedbacks.

Social-ecological system (SES): A system of interacting social and ecological components. The concept emphasizes humans as part of nature.

State: A set of conditions that include the identity, functioning and structure of the system. Also called 'domain of attraction' because feedbacks tend to stabilise the system.

State shift: Abrupt, often unanticipated large-scale shift to a new state in which a social-ecological system is characterized by different feedbacks, identity and structure. Also called 'regime shift'.